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GUIDELINES FOR OBTAINING NATURAL REGENERATION OF WHITE SPRUCE IN ALASKA

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ABSTRACT

Basic requirements for natural regeneration of white spruce are outlined. Methods are recommended for creating conditions which meet these requirements, and survey techniques are summarized for determining adequacy of seedbed preparation and regeneration. The guidelines are based on research conducted in western white spruce forests of Canada and minimal Alaskan observations and research.

Keywords: Forest regeneration (natural), white spruce, *Picea glauca*, timber management.

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INTRODUCTION

Harvesting of white spruce is currently being conducted on a limited scale in Alaska. At the present time no particular attempt is being made to regenerate these stands. However, there is a need to secure natural regeneration in these stands now and in those that will be harvested. This paper suggests a number of silvicultural treatments known to provide adequate conditions for the successful natural regeneration of white spruce and discusses some factors which must be considered in applying these treatments. The recommendations in this report are mainly the result of research conducted and experience gained in western Canada and of minimal Alaskan observations, primarily in the Tanana drainage. References to a particular subject can be found in Zasada and Gregory (1969).

Land managers should consider these recommendations a first approximation in prescribing harvesting methods, silvicultural systems, and site preparation for interior Alaska conditions. The practices prescribed in these first harvesting operations and their results must be well documented. This will allow the land manager to critically evaluate these practices and to accumulate information for refinement of the recommendations.

Some basic considerations for all timber harvesting are:

1. No practices or techniques should be prescribed which unnecessarily degrade primary land values (e.g., soil erosion and water quality and site productivity impairment).

2. Practices which minimize the danger to adjacent, unharvested forest stands should be prescribed (e.g., large accumulations of slash and dead or dying trees, which could be breeding sites for insects and diseases as well as creating a fire hazard, should be eliminated).

3. Forest harvesting must be considered as a management tool for obtaining regeneration as well as for the removal of the mature forest crop.

The approach used in preparing these guidelines has been to present the basic recommendations in table form (tables 1 and 2). This gives the land manager a ready reference to the recommended practices. In addition, there is a brief discussion of the rationale behind the recommendations, possible means of implementing some of them, and a list of selected references.

The basic assumptions made in preparing these guidelines were:

1. White spruce can be naturally regenerated following harvesting of mature stands. Provided there is a mineral soil or similar seedbed, it is believed that there are no limitations to natural regeneration of white spruce in this part of the taiga. However, at similar latitudes in northern Finland and Scandinavia, natural regeneration is sometimes difficult and long regeneration periods are required.

2. Natural regeneration is to be relied upon in reforesting harvested or otherwise disturbed areas. Under current economic conditions, this assumption is valid. However, where natural regeneration is unreliable, artificial regeneration will be required.

Table 1.-- **Preharvesting checklist for stand statistics and related information on soils, site, and other biological factors**

I. Stand and Tree Data

A. Basal area and volume (cubic and board foot) per acre of all trees 1 inch or larger at d.b.h.
   1. Conifers
   2. Hardwoods[1/]

B. Number of trees per acre which are 1 inch or larger d.b.h.
   1. Conifers
   2. Hardwoods

C. Height
   1. Conifers
      a. Merchantable height
      b. Average total height
   2. Hardwoods
      a. Merchantable height
      b. Average total height

D. Age (based on increment boring at d.b.h.)
   1. Conifers--average age of six tallest trees on 1/4-acre plot
   2. Hardwoods--average age of six hardwoods in sale area

E. Site index
   1. Conifers (see Farr (1967), for growth and yield of white spruce)
      a. Total height of tallest tree on 1/4-acre plot
      b. Average age of six tallest trees on 1/4-acre plot

II. Other Biological Data

A. Insect
B. Disease
C. Red squirrel

III. Soil-site Data

A. Depth of moss-organic layer
B. Depth to permafrost (if less than 3 feet below the surface)
C. Aspect
D. Slope
E. Position of stand on slope
F. Soil texture and depth

[1/] In many areas there will be more than one hardwood species. If this is the case, data should be collected for each species.

Table 2.-- Summary of recommendations for natural regeneration of white spruce and treatment evaluation following harvesting in interior Alaska

Item	Silvicultural system			
	Clearcut	Shelterwood	Seed tree	Selection
Age of stand	100 years or more.	80-120 years or more.	100 years or more.	80-120 years.
Block or strip size	400 feet wide.	100 acres.	60-80 acres.	No limit.
Residual stand	Unmerchantable stems; seed source in the form of leave strips 75-100 feet wide, averaging 80 or more square feet of basal area per acre.	40-60 square feet of basal area per acre of dominant and codominant white spruce plus unmerchantable stems.	At least 10 dominant or codominant white spruce (7-15 square feet of basal area per acre) plus unmerchantable stems.	Single tree: 60-100 square feet of basal area per acre depending on site index. Group: Openings made by removal of three to four trees up to those of an acre in size.
Harvesting:				
a. System	Full tree, tree length, or log length.	Full tree or tree length.	Full tree or tree length.	Full tree or tree length.
b. Season of year	May to November when possible.	May to November when possible.	May to November when possible.	May to November when possible.
Site preparation:				
a. Type	Mechanical or prescribed burning.	Mechanical.	Mechanical.	Mechanical.
b. Time	No later than mid-August when possible.	No later than mid-August when possible.	No later than mid-August when possible.	No later than mid-August when possible.
c. Timing	During good-to-excellent seed year, when possible.	--	During good-to-excellent seed year, when possible.	--
Assessment of site preparation	Cutting subdivided into units of 40 acres or less. In each unit, 100 milacre plots are systematically located and classified as having at least 1 square foot of mineral soil or not having this much exposed mineral soil. At least 55-65 percent of these plots should contain 1 square foot or more of mineral soil. If not, all or portions of the unit will require additional treatment. On half of these plots, the percentage of exposed mineral soil will be determined to provide an estimate of the percentage of mineral soil exposed on each unit.			Single tree: Similar to that for other systems, except that 20-30 percent of the plots must meet mineral soil requirements. Group: Openings should be examined to assure exposure of mineral soil.
Assessment of regeneration	These surveys should be conducted 4-6 years after seedbed preparation. Cutting units should be subdivided into 40-acre units, and 100 milacre plots should be distributed uniformly in each unit. On each plot the presence or absence of white spruce, birch, aspen, and other tree seedlings will be recorded. At least 50-60 percent of these plots should contain one or more white spruce seedlings which appear vigorous and free to grow. On half of these plots the number of seedlings, by species, will be recorded.			Single tree: Similar to procedures in other systems. Group: Openings should contain white spruce seedlings.

These recommendations should provide adequate conditions for obtaining natural regeneration of white spruce. Points to be stressed are:

1. Adequate allowance for seed source can be made only during the sale layout.
2. Proper management and control of the harvesting operation are important and may greatly increase the efficiency of site preparation.
3. Because of our lack of experience with these silvicultural systems and site preparation methods, it is important that all are tried on an operational basis. No one system should be adhered to until we know the success or failure of all systems under Alaskan conditions.
4. It is of utmost importance to determine the effectiveness of these systems and practices with seedbed and regeneration surveys.
5. Although these recommendations are primarily for establishing adequate white spruce reproduction, it must be kept in mind that the entire complex of vegetation will respond to the treatment and its response may in some cases be altered by the treatment prescribed.

3. The first cuts in the mature white spruce stands are to be regeneration cuts. This may not be true in young (80- to 100-year-old), vigorous stands. In these stands it might be desirable to make one or more partial cuts before the regeneration cut.

4. Even-aged management is to be practiced in areas designated for wood production. As white spruce occurs in even-aged stands, this assumption is silviculturally and ecologically valid. However, there are definitely areas in Alaska where other resources (e.g., water, recreation, scenery, wildlife) are important and may require management of multiple-aged or mixed species forests for all or part of the rotation.

5. The management objective is to form stands in which white spruce comprises 90 percent or more of the stems. This assumption is probably the most questionable for some of the following practical and ecological reasons.

a. Conditions created by the recommended silvicultural methods, particularly clearcutting, are ideal for the regeneration and establishment of the common deciduous species. If seed or a source of vegetative reproduction is available, it will be difficult, and perhaps undesirable in some instances, to prevent these species from occupying a portion of the site.

b. Northern European (Norway, Sweden, and Finland) experience indicates that mixed stands containing conifers and deciduous species may be beneficial in maintaining site productivity on some sites in these northern latitudes.

6. Only those portions of harvesting and site treatment which specifically pertain to securing regeneration are considered. Regulation of cut, cutting cycles, and application of the various silvicultural systems in time and space are other important aspects of harvesting and forest management which must be considered in a well-organized harvesting program. For a detailed discussion of these considerations the land manager is referred to texts on forest management and silviculture.

7. These guidelines provide a basis for regeneration practices during the next 10 years. After this time, the guidelines should be updated and changes made where practice and research indicate that they are needed.

SILVICULTURAL PRACTICES FOR OBTAINING NATURAL REGENERATION OF WHITE SPRUCE

White Spruce Silvics and Ecology

The white spruce type consists of pure or mixed stands in which the white spruce is even-aged. Although these stands occur on a variety of sites, their best development is on river bottom and certain favorable upland sites. These river bottom sites occur throughout the range of white spruce in Alaska. They are generally characterized by silt-textured surface soils of alluvial origin deposited over coarser sands and gravels. These sites are flat and are usually found within one-fourth to one-half mile of the river. They are subject to periodic flooding which can result in stratified silt-organic matter soil profiles. Because of flooding, the

thickness of the moss-organic mat varies greatly.

The upland sites vary from the relatively flat plateaus in the Copper River drainage to the moderately steep south-facing slopes adjacent to the Tanana River flood plain. Soils on these sites vary in origin; common parent materials include loess, glacial tills, and lacustrine deposits. Upland stands have relatively thick uniform moss-organic layers which are commonly 8 to 10 inches thick.

On the south-facing slopes of the Tanana drainage, permafrost is non-existent or at least does not occur in the surface 4 to 6 feet of soil. North and south of the Alaska Range permafrost, or at least frozen soil lasting into August, has been observed on river bottom and upland white spruce stands. The reaction of permafrost to harvesting and site preparation needs investigation.

Development of understory vegetation on these sites varies considerably depending on overstory conditions. Because white spruce covers such a wide range in Alaska, the understory varies accordingly. The more common shrub and herbaceous species are alder (*Alnus* spp.), willows (*Salix* spp.), rose (*Rosa acicularis*), highbush cranberry (*Viburnum edule*), dwarf dogwood (*Cornus canadensis*), blueberry (*Vaccinium uliginosum*), menziesia (*Menziesia ferruginea*), grasses (mainly *Calamagrostis purpurascens*), raspberry (*Rubus pedatus*), fireweed (*Epilobium angustifolium*), horsetails (*Equisetum* spp.), twinflower (*Linnaea borealis*), bluebell (*Mertensia paniculata*), and pyrola (*Pyrola* spp.).

Commonly associated tree species are paper birch (*Betula papyrifera*), quaking aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*), black cottonwood (*P. trichocarpa*), mountain hemlock (*Tsuga mertensiana*), and, to a lesser degree, black spruce (*Picea mariana*). Paper birch, aspen, and hemlock are more common on upland sites and balsam poplar and cottonwood, on river bottom sites.

White spruce's place in plant succession is definitely in the later seral stages. However, whether it is the climax species, especially on river bottom sites, is not fully understood. On river bottom sites, white spruce usually develops in the understory of balsam poplar and black cottonwood stands, eventually replacing them. As the white spruce stand develops, however, site deterioration, related to thickening of the moss layer, and consequent reduced soil temperatures and permafrost may occur. The result is replacement of the white spruce by a black spruce or black spruce-open bog type.

White spruce, on upland sites, forms pure even-aged stands following disturbance (mainly fire) or, as on the river bottom, develops as an understory, gradually replacing the birch and aspen. White spruce may be the climax species on these sites, but such factors as fire and thick organic layers, which prevent regeneration, complicate this sequence.

Adequate supply of viable seed.--This is the most basic aspect of natural regeneration. Without an adequate seed source, manipulation of the seedbed and competing vegetation is a wasted effort. Unless an adequate seed source is provided prior to harvesting, prompt natural regeneration will not occur, and artificial seeding or planting will be required to adequately stock the area. Adequacy of seed supply is a function of the quantity and quality of the seed produced and the

distance that adequate quantities of seed are dispersed from the seed source.

In some years, seed quantity and quality may be a limiting factor in these subarctic forests for several reasons. First, excellent seed crops appear to occur at 10- to 12-year intervals. This interval may even be greater on marginal sites. Second, although good seed crops occur between excellent seed years, red squirrels may and frequently do harvest most of the cones. Finally, preliminary Alaskan data indicate that in some years, summer weather conditions may prevent maturation of seed crops. This has been documented in northern Finland and Scandinavia, but the extent or degree of importance of this factor in Alaska has not been determined.

Seed production by individual stands has been determined to vary between zero and 10 million viable seeds per acre. Production by individual trees in closed stands has been estimated to be between 35,000 and 38,000 seeds in good seed years. In excellent seed years, production may double. Release of trees in seed tree and shelterwood systems may stimulate production of seed, but viability may decrease because of poor pollination (particularly in the seed-tree system).

Seed dispersal into the harvested area will depend on wind velocity and direction at the time of abundant seedfall (late August to December), seed crop quantity and quality, density of the seed source, and seedfall characteristics. Based on observations from western Canada and Alaska, seed dispersal in quantities adequate for natural regeneration is not dependable beyond 300 to 400 feet from the windward side of the seed source.

Optimum seedbed conditions.-- A mineral soil seedbed generally provides the most desirable conditions for germination and first growing season survival. Canadian experience indicates that this condition is not created by logging. Therefore, site preparation is necessary.

Reduced competition.--This relates primarily to reducing competition for light, water, and nutrients to obtain rapid seedling growth and establishment. Reduction in vegetative competition occurs during overstory removal and site preparation.

Shade.-- This variable is most important during the first growing season, as it reduces soil temperatures and evaporation from the soil surface. The most desirable shade-producing objects are nonliving materials (e.g., limbs, dead trees, downed logs, depressions), overstory (e.g., shelterwood), or both. Shade produced by shrubs and herbaceous species may be beneficial during germination and first-year establishment, but the presence of these species for later development is generally detrimental.

Preharvesting Stand and Site Inventory

The preharvesting stand and site data are summarized in table 1. The stand and tree measurements are routinely included in the preharvest cruise and need no explanation. However, there are several points which require further discussion.

First, the hardwoods are frequently disregarded when cruises are made for white spruce saw-log volume. However, information concerning the density of this species is important for determining their regeneration potential. These measurements may also be of some value in the future for general comparison of growth of different species on the same sites.

Site index is important as an indication of site productivity. This value cannot be accurately determined once the stand has been harvested, because current white spruce growth and yield tables are based on total height and tree age and have not been correlated with soil or other site variables. Determination of site index for white spruce requires total height of the tallest tree on a 1/4-acre plot and breast height stand age found by averaging the age (found by increment boring at d.b.h.) of the six tallest trees on a 1/4-acre plot.[1/] At least four plots should be examined in order to obtain an average for the stand.

Although many of the variables mentioned under the soil-site data in table 1 are considered by the land manager in the course of timber sale layout, they are not always recorded or treated in the same detail that the stand and tree data are. These observations are at least as valuable as the stand data to the land manager. In conjunction with the stand and other biological data, these soil-site data are potentially valuable in prescribing harvesting and silvicultural systems, site preparation methods, and road construction. If questions arise concerning harvesting and site preparation as a result of site and soil observations, the land manager should consult with a soil scientist or other specialist. A brief discussion of the variables in table 1 is presented below.

Depth of moss-organic layer.-- Knowledge of this variable is important for determining the amount of material which needs to be removed by site preparation. Thickness of this layer can be determined by digging through it and measuring depth to the mineral soil surface. A minimum of 20 points, distributed throughout the stand, should be sampled.

Depth to permafrost.-- Permafrost has been observed in some white spruce stands in Alaska and not in others. Until the nature and pattern of occurrence is known, this observation should be made in all stands before logging. The presence or absence of permafrost is best determined by digging a soil pit. These pits should be 3 feet deep and located in four different parts of the stand. Observations must be made in August or September, as this is when the depth of thaw is greatest and seasonal frost is melted. If permafrost is found at a depth of 24 inches or less, the frozen layer should be dug through to determine its thickness. If the permafrost is at shallow depth and determined to be of considerable extent, consideration should be given to not harvesting the stand; a soil scientist should be consulted.

Aspect, slope, and slope position.-- With regard to regeneration, these variables can have bearing on site preparation and harvesting methods. In short, they can determine whether or not some of the methods recommended in this paper are applicable. In addition, more detailed knowledge of these variables can indicate, among other things, potential erosion problems, permafrost conditions, soil depth, and soil drainage.

Soil depth and texture.-- Soil observations can be made in the soil pits dug for permafrost observations. On a clean wall of the soil pit, measurements can be made of depth to bedrock (upland sites) or gravel (river bottoms), texture of the surface soil (sand, clay, silt), and percent of stone in the surface 2 feet of the soil.

The biological observations included here are only those which are easily

[1] See Farr (1967) for white spruce growth and yield tables.

observed and which might affect the windfirmness of the seed source or might have detrimental effects on the residual stand or adjacent uncut stands. There are a host of biological factors (e.g., small mammals, insects, disease, vegetative composition) which may seriously affect regeneration but which require detailed study.

Insects.-- On sample plots, the trees should be examined from ground level to 6 feet for insect activity. If sawdust in bark crevices is observed, further examination should be made to determine whether or not the insects are still present. If the spruce beetle, *Dendroctonus rufipennis*, is present on two or more standing, green trees per acre, an entomologist should examine the stand to determine the extent of the problem.

Disease.-- On each plot, trees should be examined for external signs of decay. Increment borings for stand-age determination should also be examined for evidence of decay. The degree of decay present will influence windfirmness of the stand and the choice of silvicultural system.

Squirrel activity.-- These observations will assist the land manager in assessing potential seed supply problems. Although difficult to quantify, the presence of active cone caches and squirrels indicates established squirrel populations in the area. Therefore harvesting, which will restrict the squirrels' food supply (white spruce cones), may mean reduction in seed available for natural regeneration due to increased squirrel activity in the residual stand. Possible solutions would be control of squirrel populations or banding of the residual seed source.

Overstory Treatment and Seed Source Regulation

The commonly recognized silvicultural systems (clearcut, shelterwood, seed-tree, and selection) or variations of them can be used to create conditions under which white spruce will regenerate. However, the uniform shelterwood and clearcut systems are most commonly recommended, with the latter system most often used. Prescription of one of these methods must be based on the site condition and location of the stand. Current controversy over the use of clearcutting may limit its use. Where esthetics or minimal site disturbance is important, the shelterwood (or perhaps selection) system may be most desirable.

The land manager should consider that the first cut need not be a regeneration cut when prescribing a silvicultural system. In younger (80- to 100-year-old), thrifty white spruce stands, it may be desirable to make a partial cut (one of the various types of thinnings[2]) to release selected crop trees. These stands can then be left for an additional period of time (10 to 20 years) before the stand is regenerated.

Clearcut system.-- For natural regeneration, the size and shape of the clearcut block or strip must be determined by the distance that adequate quantities of seed are dispersed into the cutover. As mentioned above, adequate quantities of seed cannot be relied upon at distances beyond 300 to 400 feet from the seed source. Thus, no portion of a clearcut should be more than 400 feet from a seed source.

[2]See Hawley and Smith (1962) for a detailed discussion of partial cutting and thinning.

Leave strips should be 75 to 100 feet wide and contain a minimum of 60 to 80 square feet of white spruce basal area per acre. If the seed source does not contain this much white spruce or is not favorably oriented to prevailing August-December wind direction, clearcut size must be reduced or the seed-tree or shelterwood systems used. Practically speaking, it will be impossible to achieve optimum orientation of the seed source in all cases.

Some other factors which have to be accounted for when prescribing this system are:

1. Conditions created by the clearcut system are ideally suited to seed and vegetative regeneration of the less tolerant deciduous species. High densities of paper birch, and to a lesser extent, the *Populus* species, in the leave strips mean that much greater quantities of hardwood seed may reach the cutover than white spruce seed. Paper birch can produce much larger seed crops at more frequent intervals than white spruce. These species will prevent maximum white spruce seedling growth and establishment. In extreme cases they could significantly reduce white spruce seedling survival.

2. Leave strips, which are left as a source of seed, pose several questions. First, they are often considered uneconomical to log because of low volume and inaccessibility of some areas. This will be true unless the total harvest for a management unit is well planned for a period of years. Regulation of cut and cutting cycles are beyond the scope of this paper, but any of the current books on forest management provide a full discussion of this subject.

Secondly, regeneration of leave strips must be provided for. One alternative is preharvesting scarification. This can be accomplished at the same time that site preparation is conducted in the harvested area. The leave strip can be harvested in the winter when the seedlings are covered with snow to minimize damage. Other options are to delay harvesting of the leave strips until the adjacent stand reaches seedbearing age, leave seed trees, or remove the leave strip and artificially seed or plant the area.

Shelterwood system.-- Selection of the shelterwood stand will depend on two variables. First, in almost all cases it will be most desirable to create a uniform shelterwood, that is, the trees will be uniformly distributed over the harvested area. The individual trees can be selected either randomly or systematically. An option to the uniform method that has been used elsewhere is the alternation of narrow cut-and-leave strips. In this system the cut-and-leave strips are so oriented that the leave strips provide shade for the seedlings in the cut strips. This type of system has some possible advantages over the uniform system if highly mechanized logging systems are used.

Secondly, the number of cuts which will be used to remove the overstory will determine the residual stand. In the mature stands (100 years and older), the two-cut system is recommended--i.e., the first cut will remove all of the trees except the shelterwood; the second cut, which can occur any time after the seedlings are established, will remove the shelterwood. In stands less than 100 years old, it may be desirable to prescribe a partial cut prior to the regeneration or shelterwood cut; this would create a three-cut system.

Based on these recommendations (i.e., the uniform shelterwood and the two-cut system) the following criteria should be used to select the residual stand.

1. Trees should be windfirm dominants and codominants. This will be determined in part by selection of those trees which have no external evidence of structural damage or disease. Another factor which will be very important is damage done to these trees during harvesting. For this reason the trees should be well marked and the logger instructed to stay away from them as much as possible.

2. Trees which appear to have been good cone producers in the past should be chosen over those showing no evidence of past cone production.

Shelterwood removal can occur when the area is adequately restocked with white spruce regeneration. On timber production areas the overstory should be removed before it adversely affects seedling growth and development. This period will vary with shelterwood density. In some areas where esthetics is an important consideration, the land manager may want to maintain a two-layered stand.

Within limits the shelterwood system gives the forest manager an opportunity to control other components of the vegetation. By adjusting the residual stand density and composition, certain species can be favored. If it is desired to eliminate or greatly reduce the deciduous species, all potentially seed-bearing trees of these species can be removed. (This does not eliminate vegetative reproduction.) On the other hand, by manipulating overstory density, conditions most desirable for germination, growth, and establishment of spruce, and conditions less desirable for seed and vegetative reproduction of paper birch, aspen, balsam poplar, and black cottonwood can be created.

Two disadvantages which must be considered in applying the shelterwood and seed-tree methods are windfirmness of the residual forest and damage to the seedling stand upon removal of the residual stand. Windbreakage and windthrow have been disadvantages to the application of these systems in southern white spruce forests. Factors which must be considered in this regard are sudden opening of the stand and the ability of the selected individuals to withstand this treatment. Trees showing external physical damage or decay signs should not be selected. The extent to which this may be a problem in these subarctic forests is not known.

Damage to the seedling stand during the harvesting of the shelterwood will depend on the size of the seedlings when the overstory is removed. If accomplished when the seedlings are small and covered with snow, very little damage may be done. In any case, harvesting of the residual stand must be carefully planned in order to avoid excessive damage to the seedlings. In dense seedling stands, some thinning caused during removal could be beneficial.

Seed-tree system.--The seed-tree system relies upon residual trees uniformly distributed throughout the harvested area to provide seed for natural regeneration. This is similar to the shelterwood system except that the density of the trees is much lower than in the shelterwood and they provide little, if any, protection to the seedlings. The number of trees required per acre will be determined by the quantity and quality of seed produced by the individual trees. A minimum of 10 dominant or codominant trees per acre (7 to 15 square feet of basal area) should provide enough seed if a mineral soil seedbed is available. Criteria used to select seed trees are similar to those discussed for the shelterwood. The size of seed-tree units should be limited to 60 to 80 acres.

This system must be tested as it may have wide application in Alaska. First, it may provide an acceptable alternative to clearcutting, or it may be used with clearcutting to increase the size of cutting units. In remote river bottom stands, accessible only in winter, the seed-tree system provides a seed source without leaving large residual stand volumes, as in the leave strips in clearcutting and shelterwood stands. The advantage here is twofold--the majority of the volume is harvested and if the seed trees cannot be removed after the regeneration period, there is minimal economic loss (in terms of unharvested trees); and, although the seed trees will compete with the regeneration for growing space, the competition will be less than in a shelterwood.

Because of the potential limitations placed on natural regeneration of white spruce by red squirrels, this method and the shelterwood method should be thoroughly investigated. Spacing the seed trees or residuals of the shelterwood far enough apart prevents squirrel movement from crown to crown. Banding of all, or selected, trees in these residual stands could greatly reduce or eliminate squirrel harvest of cones. In addition, the lower stand densities and isolated trees may reduce the attractiveness of the area to squirrels because of greater exposure to predators and the elimination of tree-to-tree escape routes.

Selection system.-- The selection system creates uneven-aged forests. It is particularly suited to the more tolerant species. Except on the Kenai Peninsula where the more tolerant mountain hemlock occurs, this system should favor the establishment of white spruce over the intolerant hardwoods. This system can be applied as either single tree selection or group selection. The main objective of both is to create conditions which are adequate for growth and establishment of white spruce. Observations indicate that white spruce seed can germinate and seedlings grow for at least several years under undisturbed overstory conditions provided a mineral soil seedbed is available. It is doubtful that adequate growth is maintained under these overstory conditions, however.

Recommended stand densities for single tree selection varies with site index. For areas with site index greater than 70, basal area per acre should be reduced to between 80 and 100 square feet per acre (trees 6.5 inches and larger). On those areas with site index of less than 70, basal area should be between 60 and 70 square feet per acre.

Stand openings created by group selection can range from those made by the removal of three to four trees up to those which are as large as an acre or more. If a significant hardwood seed source is available, the smaller openings are recommended, as birch, for example, has been observed to regenerate well in openings 60 to 80 feet wide.

The criteria for selecting trees to be retained in this system are similar to those in the shelterwood system. A prime consideration is the ability of the tree to survive following stand treatment. As in the shelterwood system, the land manager has the opportunity to essentially eliminate the hardwood seed source during marking and harvesting if he so desires.

Single tree selection has been practiced in the white spruce-fir forests of interior British Columbia. Marking guidelines for these stands included removing trees most liable to sustain severe losses over a subsequent 40-year period, removal of 800 cubic feet or more per acre, and removal of not more than 50 percent of the volume of trees 11 inches

and larger. Initial results indicated that the system failed to produce any appreciable silvicultural benefits. The objective of these cuttings was increased growth of residual stands and regeneration. Site preparation was not conducted in addition to harvesting in these trials. The most serious problem associated with this method was the high incidence of mortality due to logging. It was concluded that the system should not be condemned without further trials.[3]

The greatest potential use of this system will be in areas where minimum disturbance of the site is desired but where the land manager wants to retain white spruce. Examples of such areas are those with scenic and recreational value.

Site Preparation

The thick moss-organic layers characteristic of the white spruce forests prevent seedling establishment in much of the taiga. Thus creation of a mineral soil or mixed mineral soil-organic matter seedbed is absolutely necessary for the successful natural regeneration of white spruce. Harvesting, mechanical preparation of the site, and prescribed burning are the means of creating these conditions. In addition, slash removal, control of competing vegetation and fire, and insect and disease hazard reduction can be accomplished by site preparation.

Harvesting.-- Throughout the range of white spruce, it has been found that harvesting rarely creates the conditions required for natural regeneration of white spruce. This may be even more prevalent in interior Alaska, where the organic layers are thicker and much of the harvesting is done when the ground is frozen and covered with snow. Thus, additional mechanical site preparation or prescribed fire will almost always be necessary. However, through proper management of the harvesting operation, subsequent site preparation can be made more efficient.

There are three general harvesting systems that can be prescribed for trees of the size occurring in Alaskan white spruce forests. These are log length, tree length, and full tree logging. The log length system removes only the merchantable portion of the bole from the site. Slash reduction, if desired, must be accomplished by piling and burning or broadcast burning. Tree length logging leaves the limb material on the site. The tree is either bucked at the landing or hauled full length to the mill. Full tree logging removes the entire tree from the site. Limbing occurs at the landing and bucking at either the landing or mill. Unmerchantable bolewood and limbs can be piled and burned or chipped and returned to the site. Silvicultural advantages of the full tree and tree length system over the log length system are:

1. Removal of all larger diameter slash will reduce potential bark beetle breeding sites. Materials 3.5 inches and larger are potential breeding areas.[4]

2. Reduction of fire hazard.

3. Greater disturbance of organic layers and exposure of mineral soil (particularly true of the full tree system).

4. Destruction of more competing vegetation.

[3] See Glew (1963) for a more detailed discussion of this subject.

[4] Based on preliminary results of studies conducted by Roy Beckwith, forest entomologist, Institute of Northern Forestry, Fairbanks, Alaska.

The time of year at which harvesting is conducted is particularly important in areas where the spruce beetle is a serious problem. Two alternatives are available; both are based on the fact that beetle flight occurs in May and June. The first alternative is to remove all harvested material from the area by May and to remove any material that is felled during the period of beetle flight prior to emergence. If material must be left, it should be felled in late June or July so that it has time to dry out before the next period of spruce beetle activity (see footnote 4). There are other means of controlling beetle populations (e.g., spraying, trap-tree method); although these are additional costs they may be necessary if control through harvesting fails.

Mechanical.--Mechanical site preparation is one means of creating optimum seedbed conditions and also of reducing competition from shrubs and herbaceous vegetation. The objective of this treatment is to remove the moss-organic layer, exposing mineral soil without creating deep trenches. The shape and form of the seedbeds will depend on the scarification equipment used. To obtain uniform seedling distribution, the seedbeds must be well distributed.

There have been many different types of equipment used or developed for seedbed scarification. It has not been determined which is most efficient under Alaskan conditions. However, most equipment other than the standard crawler tractor blade is not generally available. Where scarification blades *are* available, their use should be required.

Scarification should be done, when possible, during the good seed years, before peak annual seed fall. For most efficient use of the seed crop, this would be before mid-August as seed fall can commence any time after that, with the majority of the seed dispersed by December.

Seed produced during a 2- to 5-year period may be required to naturally regenerate a cutting. This means that seedbeds must remain relatively free of competition during this period to assure satisfactory conditions for growth and seedling establishment. In other areas, the larger the seedbed, the longer it will remain satisfactory for seedling establishment. Minimum size of scarified patches should be 4 to 6 feet in the smallest dimension.

A limitation to mechanical seedbed preparation is the slope on which scarification can be efficiently or safely conducted. Canadian experience indicated that slopes over 30 percent are difficult to scarify. Alternatives to mechanical seedbed preparation are hand-scarification and prescribed fire. On these sites natural regeneration may have to be replaced by planting as this latter method requires less exposure of mineral soil. Regardless of slope, mechanical seedbed preparation should be conducted parallel to the contour to minimize erosion.

The above discussion related primarily to site preparation on areas where the clearcut, shelterwood, or seed-tree systems have been used. It is obviously important that a large percentage of the harvested area be treated and the seedbeds be uniformly distributed in these systems. In the single tree selection system, not as much area needs to be treated and a uniform distribution is not as important; in group selection, only the openings created by harvesting need to be treated.

Prescribed burning.-- Wildfire has been a predominant, and probably the most important, large-scale natural or man-caused forest disturbance in the

Alaskan taiga, with the exception of river bottoms where stream erosion and deposition have been important. Fire can create optimum conditions for white spruce regeneration, and examples of pure white spruce stands which apparently originated after fire are common. However, the seedbed conditions created by the fire will vary with such factors as fuel moisture, fuel volume, and weather conditions at the time of burning. Fire may also be important in recycling of nutrients and maintaining site productivity in these forests.

Prescribed fire has not been used as a management tool in Alaska. There is little doubt that one or several prescribed fires may be the most economic means of creating optimum conditions for white spruce regeneration and for reducing slash concentrations on harvested areas. However, experience in Canada has indicated that prescribed fire alone does not create adequate seedbed conditions and that it must be used in conjunction with mechanical site preparation. Because white spruce is easily killed by fire, clearcutting would be the only silvicultural system that could be used with this site preparation method. The method of harvesting chosen will also affect the intensity of the burn as fuel accumulation will vary significantly between log length, tree length, and full tree harvesting systems.

Prescribed burning must be conducted to determine its effectiveness under Alaskan conditions and to compare it with other methods of accomplishing similar ends. Any study of this method should include the examination of long-term effects of these treatments on site productivity.

SURVEY CHECK OF ADEQUACY OF SITE PREPARATION AND REGENERATION

The cutting must be surveyed, following seedbed preparation and before the equipment leaves the area, to determine adequacy of seedbed preparation. These surveys should be conducted on blocks no larger than 40 acres, which means subdividing some cuttings into two or more units. Within each unit, 100 milacre plots must be systematically located and examined. A plot will be determined satisfactory if it contains at least 1 square foot of exposed mineral soil. The plots should be so located that the entire area is represented in the survey. On alternate plots (i.e., 50 of the milacre plots), the percentage of mineral soil exposed must be determined; this will provide an estimate of the amount of mineral soil exposed on each unit. The survey lines should be oriented perpendicular to the general direction which the equipment moved while scarifying.

For optimum mineral soil exposure, 65 percent of the milacre plots in a unit should contain 1 square foot of mineral soil. However, percentages of 55 percent or more will constitute an acceptable job. Anything less than 55 percent will require that all or portions of the unit must have additional treatment. The percentage of the total area which has an exposed mineral soil seedbed will be significantly less than the percentage of the milacre plots containing 1 square foot or more of mineral soil.[5]

Regeneration surveys should be conducted four to six growing seasons after seedbed preparation. This time-span allows for several years of seed fall to contribute to seedling production and

[5] See Decie and Fraser (1960) for a detailed discussion of this subject.

is about the length of time which scarified seedbeds will remain adequate for white spruce seed germination and seedling survival. These surveys will be similar to those conducted for evaluating seedbed preparation, i.e., 100 milacre plots systematically located in blocks not larger than 40 acres. Each plot will be classified as to the presence or absence of at least one 2-year-old white spruce; plots should also be examined for presence or absence of birch and other tree seedlings (including aspen suckers and birch sprouts). On every other plot, seedlings will be counted by species to obtain an estimate of the number of seedlings per acre. Survey lines should be perpendicular to the direction which the equipment moved while scarifying.

Sixty percent of these milacre plots must be stocked with white spruce seedlings; however, 50 percent or more will provide acceptable stocking. If stocking is less than 50 percent, additional plots and observations may be needed for evaluation of the problem and determination of possible remedies.

These survey procedures are designed for use following application of the clearcut, shelterwood, or seed-tree systems. Survey techniques will have to be adapted to meet the requirements of the selection system. In single tree selection, 20 to 30 percent of the plots should contain 1 square foot of mineral soil following site preparation; as in the other systems, 50 to 60 percent of the reproduction survey plots should be stocked with white spruce seedlings. In group selection, the openings created by harvesting should be scarified and examined for regeneration.

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